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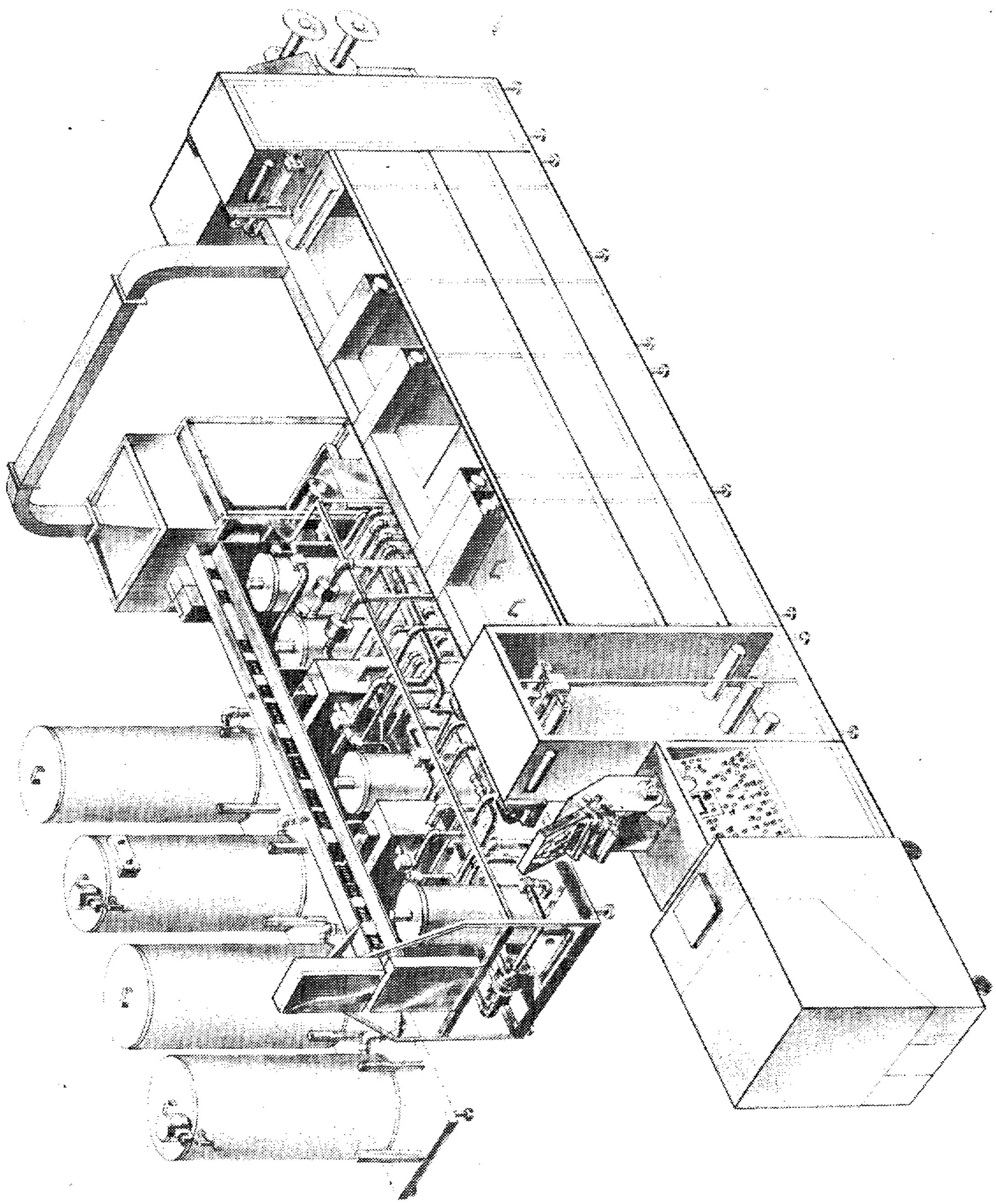
TO DETERMINE THE COEFFICIENT OF FRICTION OF FILM

STATINTL

May 1965

Sanitized Copy Approved for Release 2011/07/21 : CIA-RDP78B04747A002800120001-8



Perspective Drawing of HTA-5 Processor

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ILLUSTRATIONS

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FOREWORD

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[redacted] submits this report in compliance with Item 4-2 of the Development Objectives of Contract [redacted] This is a final report and completely supercedes the interim report of the same number submitted in February 1965 as a part of Report [redacted]

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Approved:

[redacted]

Research Manager

Good Show!
Ken.

[redacted] STAT

ABSTRACT

This assignment was issued to experimentally determine the coefficient of friction for long lengths of film submersed in aqueous solution and to develop a formula for its calculation. This friction is one of the factors contributing to film tension and, therefore, affecting bearing loads and capstan torque. Other factors (examined in Report [redacted] are the forces required to bend film over bearings and those devices required to provide tension for tracking.

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SUMMARY

This report compiles data on the coefficient of frictional force creating drag on film being moved through liquid at various speeds. Readings were obtained on 9.5-inch wide film and given as broad an application to prototype design problems as possible. By relating the data through formula and dimensionless constants, practical situations can be handled by simplified calculations. Typical prototype design parameters were selected for a hypothetical processor, and the results of the calculations were analyzed in the context of producing a workable machine.

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SECTION 1
INTRODUCTION

In conventional processing machines, the film is moved over a series of driven and idler rollers and clutches to control the tension of the film between rollers. The skin friction of film in these machines is of such a low value, when compared to the torque at each driven roller, that it can be ignored. Since the air or liquid cushion over which the film is transported is virtually frictionless in a liquid/air-bearing processor, the tension in the film is generated from another source. In the HTA-5 processor, this tension was evidenced only during transport; there was no tension in the film at rest.

In the HTA-5 processor, the total drag on the system is the result of several components:

1) The force required to bend film

2) The frictional drag of long lengths of film passing through aqueous solutions

3) The additional load imposed by tracking and tensioning devices, dancing rollers, etc.

In contrast to the roller-type processor, the frictional drag of the film becomes a significant part of the total system load. Testing experience has shown that this figure is far from negligible. Since neither theoretical nor empirical data existed with which the design engineer could predict processor performance, two projects were initiated to fill this technological gap. The first project was assignment [redacted] STAT which determined the bending force required for different thicknesses of film around varying radii. The second project was this assignment, designed to experimentally determine film frictional drag coefficients and to subsequently reduce the data to mathematical formulae. A combination of the two components of drag will produce dependable design parameters.

Preliminary work in a swimming pool with 20-foot lengths of film indicated that for 20 feet per minute, a 3-ounce tension was generated by drag forces. This figure converts to 24 ounces for the length of film in the HTA-5 processor, or a bearing load of 3 pounds. The cushion depth of the last bearing in the HTA-5 processor was measured while film was being transported at a speed of 20 feet per minute. A similar bearing was mounted on a test stand and, using the processor blower with the output adjusted to an identical manometer pressure, the cushion was loaded until an equivalent depth was obtained. A total weight of 3-3/4 pounds was required. If the additional bending forces are considered, this weight is compatible with the 3-pound load extrapolated from the swimming pool tests.

SECTION 2

TECHNICAL DISCUSSION

2.1 COEFFICIENT OF FRICTION

To obtain accurate figures of the coefficient of friction of film, a tow tank was considered. To keep the percentage of errors low in comparison with total friction values, however, a long length of film must be towed. A tank large enough to permit such a test would have to be at least 120 feet long and therefore impractical and too costly. As a practical alternative, a floating test rig was designed and built (Figures 2-1 and 2-2). The float was constructed of 1/4-inch thick commercial plywood and filled with styrofoam sheets.

The test gear mounted on the float consisted essentially of an electric drive motor with a speed control. The motor was used to drive a pulley of exactly 1-foot circumference. A small takeup motor and reel were also used.

The length of test film was attached to a monofilament nylon line which passed under the float and over a roller to the pulley. The line was wrapped one complete turn around the pulley and secured to the takeup motor reel. At each revolution of the pulley, a microswitch closed to operate a digital counter. A stopwatch was used to make an accurate adjustment of the film wind-in rate.

The test rig was attached through a dynamometer to a fixed point so that the drag pull on the line when the film was wound in could be read as a reactionary force on the test-rig anchor point (Figure 2-2). The float, despite its total weight of 63 pounds, was essentially frictionless in the configuration used.

2.2 FLOATING TEST RIG RESULTS

Test runs were obtained from trial use of the rig at a marina where power and facilities were available; however, due to winds, passing vessels, and a strong, variable tide, these figures are too inaccurate for use. An inland body of still water was then located and the test repeated. The measured values of drag at low speeds were less than the coefficient necessary to keep the float in alignment, and variations in alignment introduced errors of the same magnitude as the reading.

2.3 REDESIGNED TEST APPARATUS

In order to obtain the sensitivity necessary, the test apparatus was redesigned to mount dockside (Figures 2-3, 2-4, 2-5, and 2-6). The same pulley and reel takeup unit was mounted on a rigid plywood panel which was then suspended by four thin stainless steel cables from a trussed wooden framework. The floating panel was carefully balanced by counterweights and both the framework and panel accurately levelled for the test series in such a way that tension on each of the four suspension cables was equalized. The tow line was guided by two pulleys so that it was introduced below water level at the same depth as the towed film. Inaccuracies introduced by the pendulum effect of the panel were negligible; the maximum total movement at the highest reading was about 0.200 inch. A more sensitive dynamometer (Chatillon Model DPP-5, Serial 2740) was obtained for the test. This instrument read o to 5 pounds in 0.05 scale increments.

Four refinements in the takeup mechanism improved the accuracy of measurement and the reproducibility of readings:

1) Addition of an oscillating lead screw to feed the line evenly to the takeup reel

2) Covering the surface of the measuring drum with fine abrasive emery paper to prevent slippage

3) Placing three sets of rollers on the drum periphery to keep the takeup-line spiral in alignment

4) Substituting braided nylon squidding line (stretch-controlled, waterproofed, 72-pound test) for the monofilament type used previously.

The oscillating lead screw was found necessary because, if the line were permitted to wind randomly on the takeup reel, pulsations were introduced in the dynamometer making accurate reading impossible. Before the abrasive paper was applied to the measuring drum, its diameter was reduced sufficiently to cause the finished size (abrasive plus adhesive) to be exactly 1 foot ±.001 measured to the centerline of the wetted nylon line. Any error introduced here would be multiplied by a factor of 120 at the highest measured film velocity.

A stable tow rig was constructed on the catamaran principle by which a bridle attached to the film was held seven inches below the water surface between two 40-inch long wooden hulls. A tare reading at each measured speed was obtained by towing the rig with a two-foot piece of film attached. This reading represented the total drag of the nylon line, the tow rig, and supporting bridle. It was subtracted from each drag coefficient measured on the long film.

2.4 TEST PROCEDURE

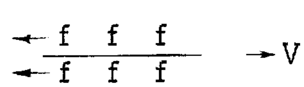
The film used for all tests was Type SP-952, black aero leader, acetate base, 9-1/2 inches wide by 4.7 mils thick. The length used was 52 feet, which gave the resistance of 50 feet when the tare was subtracted. The data are summarized in Figure 2-7 and Table 2-1.

Errors in speed determination were minimized by synchronizing the stopwatch as carefully as possible with the microswitch trip and making each run as long as the 300-foot width of the lake permitted. At the start of each of the runs with the long length, the film was carefully unrolled behind the drag float as it moved forward so that it formed a smooth flat ribbon. The reading was not taken until the system had stabilized. Only one test point (Figure 2-7 at 60 feet per minute) is out of line and it is felt that the curve represents an overall close correlation of the true drag coefficients.

A cursory analysis of the apparatus might lead to the conclusion that the inertia of the panel and the friction of the various pulleys, eyelets, and bearings used are all part of the measured drag coefficient. This is not true. If a vector diagram of the takeup mechanism is drawn in which the pendulous panel and pulley attachments are considered a complete isolated "floating" system, then it can readily be seen that the line pull is transmitted directly to the dynamometer.

2.5 MATHEMATICAL FORMULA

When any body is moved through water at a velocity, V, there is a drag or resisting force, D, exerted by the water on the body moving through it. In the case of film or thin flat plates of little or no frontal area, this force is known as skin friction



This force may be calculated from the following equation:

$$D = C_f \rho \frac{V^2}{2} \cdot S \qquad (1)$$

where

- D skin friction force in pounds
- C_f dimensionless coefficient
- ρ mass density of the liquid in slugs per cubic feet
- S wetted surface area in square feet
- V velocity in feet per second.

Note that ρ of water at a temperature of 20°C is 1.937 slugs per cubic foot and

$$D = \frac{lbs}{ft^3} \times \frac{sec^2}{ft} \times \frac{ft^2}{sec^2} \times ft^2 = lbs$$

The drag coefficient C_f is mainly proportional to the Reynolds number, a dimensionless figure expressed as:

$$R_e = \rho' \frac{VL}{\mu} \qquad (2)$$

where

- V velocity in feet per second
- L length in feet
- ρ' density in pounds per cubic feet
- μ kinematic viscosity in pounds per foot-second.

The viscosity of water in cgs units (centipoises or grams per centimeter-second) can be converted to the English system (pounds per foot-second) by multiplying by the factor 0.000672. Viscosity is extremely temperature sensitive, varying widely for small incremental changes.

Solving equation (1) for C_f gives the following expression:

$$C_f = \frac{2D}{\rho S V^2} \qquad (3)$$

Substituting values for velocity of 20 feet per minute and temperature of 61°F gives:

$$C_f = \frac{2 \times 0.22}{1.938 \times \frac{9.5}{12} \times 200 \times 20^2}$$

$$= 3.59 \times 10^{-6}$$

Values obtained in this manner and corresponding Reynolds numbers were tabulated (Table 2-2) and graphed (Figure 2-8).

2.6 EXAMPLE OF PROCESSOR CALCULATION

2.6.1 Film Parameter Specification

A typical example of the use of these charts and data for the calculation of a hypothetical processor proves the simplest method for illustrating the mathematics and logic of the approach. In the last analysis, the finished design will always depend upon the parameters

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set by the desired results in terms of film type, speed, gamma, resolution, granularity, acuity, and image quality. Assume that the design specification called for the processor to handle aerial film Types 4400, 4404, and 5427 to the following criteria:

Gamma	2.2 ±0.1 *
Granularity	2.60 to 2.70 (D_{net} = 1.0)
Net Density	1.0 ±0.2
Resolution	50 to 60 (T.O.C. 1000:1)
Fog Level	<0.4
Processing Speed	20 fpm

2.6.2 Processor Sizing by Film Length

Momentarily setting aside consideration of the accumulator where the total required internal footage is dictated by the dwell time needed for splicing, the developer section can be determined. The manufacturer's data sheets (References 1, 2, and 3) show that an average development time of 8 minutes at 68°F in D-19 developer most closely encompasses the desired quality standards listed above. Translated into film length in the developer section, this would require 160 feet at 20 feet per minute to assure proper dwell time.

Assuming a bend radius of 2-1/2 inches at each bearing, the length of the semicircular return loop would be:

$$\text{Return Loop Length} = \pi \times \frac{2.5}{12} = 0.655 \text{ feet}$$

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* SAC generally prefers a gamma of 2.2 to 2.3 with negative aerial film, and TAC a gamma of 1.0. Both use 4 DS developer at 75°F. For duplicating film, 16 D developer is generally employed at 70°F.

As a first approximation, the bearings of the [redacted] EH-49 Controllable Development Processor (deep-tank processor) were approximately 60 inches apart on vertical centers. Therefore, the number of bearings required in the developer section (Figure 2-9) would be:

$$\text{Number of Bearings} = \frac{160}{\frac{60}{12} + 0.66}$$

$$= 28.27$$

This figure would be rounded out to 29 since one extra bearing is required on the bottom row in each processor section in order to get the film in and out of the tank. If the customer were to insist on no variation in normal developing time (i.e. 68°F for 8 minutes) and no deviation from specified speed (20 fpm), the configuration would be set at 29 bearings. Since this number is more than three-fourths the total number of liquid bearings used in one of the largest [redacted] processors, the HTA-5 (frontispiece), the total length of the unit would exceed by almost one-half the present length of 26 feet, 2 inches when load and takeup reels are in position. If space and cost were a prime consideration, then at least two alternate courses for reducing design size are open.

In a closely-written specification, one customer requested the design of a processor in which the development could be controlled during its cycle. The resulting equipment was compact and performed laudably. Mentioned previously, this machine was called the CDP and worked in this manner. The temperature and dwell-time selected for the developer tank gave approximately 25 percent normal development. By means of an infrared scanner and computer-controlled densitometric comparator, a series of heat shocks was administered to the film during development to

[redacted]

bring it up to normal gamma. This is one possible means of reducing size but not cost. Specifications for four typical [redacted] Processors are included (Tables 2-3 through 2-6) to provide realistic background for the ensuing calculations.

In the present case, the data of Report [redacted] (Reference 4) shows that developer D-19 with a processing temperature of 88°F for 1 minute, 15 seconds will satisfactorily bracket the specification parameters for film Types 4400 and 4404. In terms of film lengths, this new figure would require only 25 feet in the developer. In the special case of Type 5427 duplicating film, however, a dwell time of 2 minutes, 10 seconds (equivalent to 43-1/3 feet) would be required at a temperature of 88°F to give satisfactory results. The vertical spacing for bearings to give a total of 43-1/3 feet in the tank are tabulated below:

Number of Bearings	5	7	9
Vertical Spacing	6 ft, 8 in.	4 ft, 10 in.	3 ft, 8 in.

The choice between 7- and 9-inch bearings then becomes merely a matter of economic considerations, special limitations (intended location and room height versus length) and operator convenience. The higher number of bearings was arbitrarily selected for this design which gives a 3-foot, 8-inch bearing spacing. The faster development (75 seconds) required for film Types 4400 and 4401 could be attained in a number of ways. Bypassing four bearings would be one method. A mechanical means for decreasing the vertical spacing is another. The developer chemical composition could be changed or the temperature lowered. These latter alternatives are obviously less satisfactory than the first two and either would call for additional detailed research.

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References 5 through 11, which deal with residual thiosulfate determinations and accelerated processing formulae, substantiate the remaining film lengths and dwell times selected. These have been tabulated (Table 2-7) and illustrated (Figure 2-9).

2.6.3 Calculation of Film Drag

To obtain values for substitution in Equation (1), read ρ'/μ from Figure 2-10 at 88°F as 11.65×10^4 and calculate the Reynolds number for the assumed conditions. From Table 2-7, the wetted length of film, L, is 160-1/3 feet. Substituting in Equation (2) gives:

$$R_e = \rho' \frac{VL}{\mu}$$

$$= 11.65 \times 10^4 \times 20 \times 160.3$$

$$= 3.74 \times 10^8$$

Read a value of 1.52×10^{-6} for C_f from Figure 2-8. Read mass density for water at 88°F from Figure 2-11 as 1.934. Read nomograph, IB in Figure 2-13 for S of 9.5-inch film, 160.3 feet long, as 255 square feet. (The edge of the film was not considered in setting up the surface calculations for the nomographs.) Substituting in Equation (1) gives:

$$D = C_f \rho \frac{V^2}{2} \cdot S$$

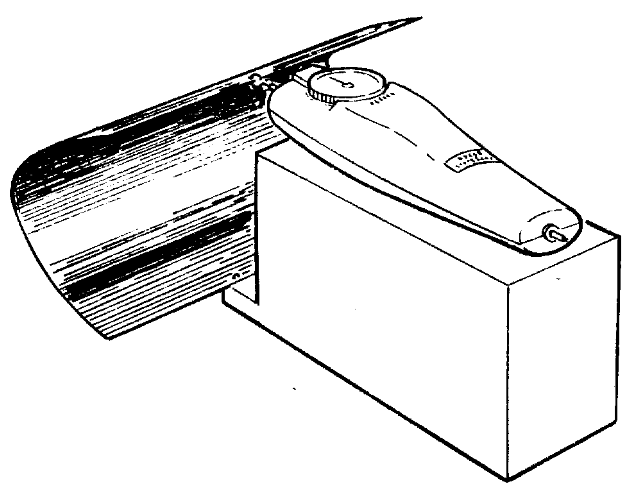
$$= 1.52 \times 10^{-6} \times 1.934 \times \frac{20^2}{2} \times 255$$

$$= 1.50 \text{ pounds.}$$

2.6.4 Calculation of Bearing Loads

The data in Figure 9 of Report [redacted] (Reference 12) apply only to the roller bearings of the accumulator. They were obtained by adding known weights to various types and widths of film and leader (cut to 15-inch lengths) until the film conformed exactly to horizontal cylinders of fixed diameter (1/2, 1, 2, 3, and 5 inches). They are of academic interest only in these calculations since each driven roller can be considered a capstan and, thus, does not present an initial load to the head end of the wet section. (See Subsection 2.7 for detailed duscussion.) STAT

In this hypothetical air/liquid bearing processor, however, the film does not touch the bearing surfaces but floats over them. With this effect in mind, two tests were performed using a different mode of measurement:



In these tests, lengths of heavy-base leader (8.5 mils in thickness representing the condition of greatest load for the system) were cut slightly longer than required for a 180-degree wrap at the desired diameter.

The zero-to-five pound dynamometer was used to record the tension required to complete the half-wrap. The natural spring forces inherent in the film have two components at the attachment point of the dynamometer. The one normal to the film's surface acts at right angles to the movable arm and, thus, is not measured. The results are tabulated below:

	Bend Diameter 4-inch	Bend Diameter 5-inch	Temperature °F	Condition
Grey Inside	0.01 pound	0.01 pound	72.1	Dry
Grey Outside	0.025 pound	0.025 pound	72.1	Dry
Grey Outside	-	0.01 pound	100.0	Wet

This leader, as received from the manufacturer, is normally coiled with its grey side in and black side out. Thus, the measurement made against its natural set is slightly higher when the film is dry. At 100°F, however, with the film wet, this difference disappeared. The dry weight of 15.15 inches (one square foot of 9.5-inch film) was 0.06 pounds by dynamometer and 24.6 grams (equivalent to 0.054 pound) by beam balance. Immersed in water at 68°F, the weight was only 0.02 pound due to its displacement.

If these new data are substituted in the calculation for bearing load, the values become:

$$F_B = N_l \times f_w + N_a \times f_d \qquad (4)$$

where

F_B total bending force

N_l number of liquid bearings

N_a number of air bearings

f_w bending force required for wet film

f_d bending force required for dry film.

Substituting in Equation (4) gives:

$$F_B = 32 \times .01 + 5 \times 0.025 \text{ *}$$
$$= 0.32 + 0.13$$
$$= 0.45 \text{ pounds (wet end)}$$

To this should be added the film weight:

$$W_{\text{wet end}} = 160.3 \times 0.02 = 3.21$$

Therefore:

$$F_B + W_{\text{wet}} = 0.45 + 3.21 = 3.66$$

Combining this figure with the total film drag (Subsection 2.6.2) gives:

$$1.50 + 3.66 = 5.16 \text{ pounds}$$

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* The transfer bearings as well as the drive capstan and dry-box bearings are all considered operating on dry film to represent the greatest design load.

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Since the tension in processors is cumulative from tank to tank and is greatest near the takeup end of the machine, the above calculations show the maximum load to which the last liquid bearing would be subjected. The other loads were obtained in a similar manner and added to Figure 2-9. If the drive capstan is assumed to be positioned between the final wetting-agent tank and the dry box, the maximum load on any of its air bearings would be:

$$\text{Load total} = 30 \times .06 + 11 \times .025 = 2.08 \text{ pounds}$$

Even if a twenty percent safety factor is added to this and the wet bearing load figure, the total is still well within the state-of-the-art design capabilities.

The data in Report [redacted] (Reference 13) shows that the experimental methacrylate end-feed self-centering liquid bearing would support a four-pound weight on a 3/16-inch cushion with an input flow rate of 10 gallons per minute at a pressure of 0.4 pounds per square inch. This can be expressed in terms of horsepower as follows: STAT

$$HP_{input} = \overset{gpm}{10} \times \overset{ft^3/min}{\frac{1}{7.48}} \times \overset{ft^3\backslash(min)\,in^2}{0.4} \times \overset{ft\text{-}lb/min}{144} \times \overset{hp}{\frac{1}{33{,}000}}$$

$$= 0.00233$$

Slightly more than a 20-percent increase in flow and pressure should be adequate to provide support for the 5.16-pound load on the final liquid bearing. A complete set of these data are being compiled for the liquid bearing.

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The load on the drive capstan is slightly higher (5.16 plús the weight of film supported and the "dry" bend radial force required). This calculated value of 6.47 pounds would require a drive motor capable of delivering a torque of 16.2 inch-pounds, assuming an optimum diameter of 5 inches.

There remains the possibility that the last wet-section air-transfer bearing between the final wash tank and the wetting agent section might be overloaded and thus render the whole processor inoperative. Should this occur, good design engineering practice would dictate the addition of an intermediate drive capstan between the load and takeup ends of the processor. This would reduce the maximum load on the last bearing by approximately one-half. It is considered valid to use bend forces for the 4- and 5-inch radii as applied to 3-inch liquid bearings. The rationale here is that film passing over a liquid bearing will assume a bend controlled by its drag at that point and not by the diameter of the bearing. The limiting factor in this case is the horizontal spacing between bearings to prevent adjacent loops from rubbing against each other.

2.7 CALCULATION PROCEDURE SUMMARY

Calculations discussed in preceding subsections are summarized in procedure form below:

1) Obtain processed film parameter specification including operating speed desired.

2) Determine processing times, temperatures, and chemicals which will meet these specifications.

3) Translate the dwell time required in each processing section into film length and total these lengths.

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4) Select a vertical center-to-center bearing spacing for optimal tank dimensions. This may be reasonably based on the shortest process time involved wherein only a single loop might be needed.

5) Determine all semicircular return loop lengths.

6) With the values of steps 4 and 5, determine the number of bearings required in each section. Since the tank bearings must be an odd number in each case, some adjustment of vertical spacing may be necessary.

7) Calculate the Reynolds number for the wetted film length.

$$R_e = \rho' \frac{VL}{\mu}$$

Use Figure 2-10 to obtain values of ρ'/μ for a given temperature.

8) Read a value for C_f from the Reynolds number and Figure 2-8.

9) Calculate film drag D with the formula

$$D = C_f \rho \frac{V}{2} S \qquad \text{using Figure 2-11 for}$$

using Figure 2-11 for ρ and Figure 2-12 or 2-13 (the nomographs) for S.

10) Calculate liquid bearing loads with the formula

$$F_B = N_l \times f_w + N_a \times f_d$$

11) Calculate the film weight. The wet and dry weights vary, due to film displacement.

12) Total the film drag and bearing loads for both the wet and dry sections to get maximum load on the last bearing in each case.

13) Break down load figures for each section.

14) Good design calls for the addition of a safety factor to allow operational latitude. This could reasonably be selected between 10 and 20 percent.

NOTE

> Do not neglect to add in the additional loads which may result from accumulators, tensioning devices, dancing rollers, etc.

2.8 ADDITIONAL RESEARCH

The importance of the data presented in this report in directing the necessary trade-offs, while a processor is still on the drafting board, can readily be appreciated. It serves also to underline two gaps in present design data. No published data are available on the point at which load will cause permanent distortion in thin-base films at elevated (above 68°F) operating temperatures. Experimentation on the recovery characteristics of different bases and emulsions is needed. Complete data should be obtained on much more sensitive equipment for the bending forces required for air and liquid bearings with different types, thicknesses, and widths of film, both wet and dry at elevated temperatures.

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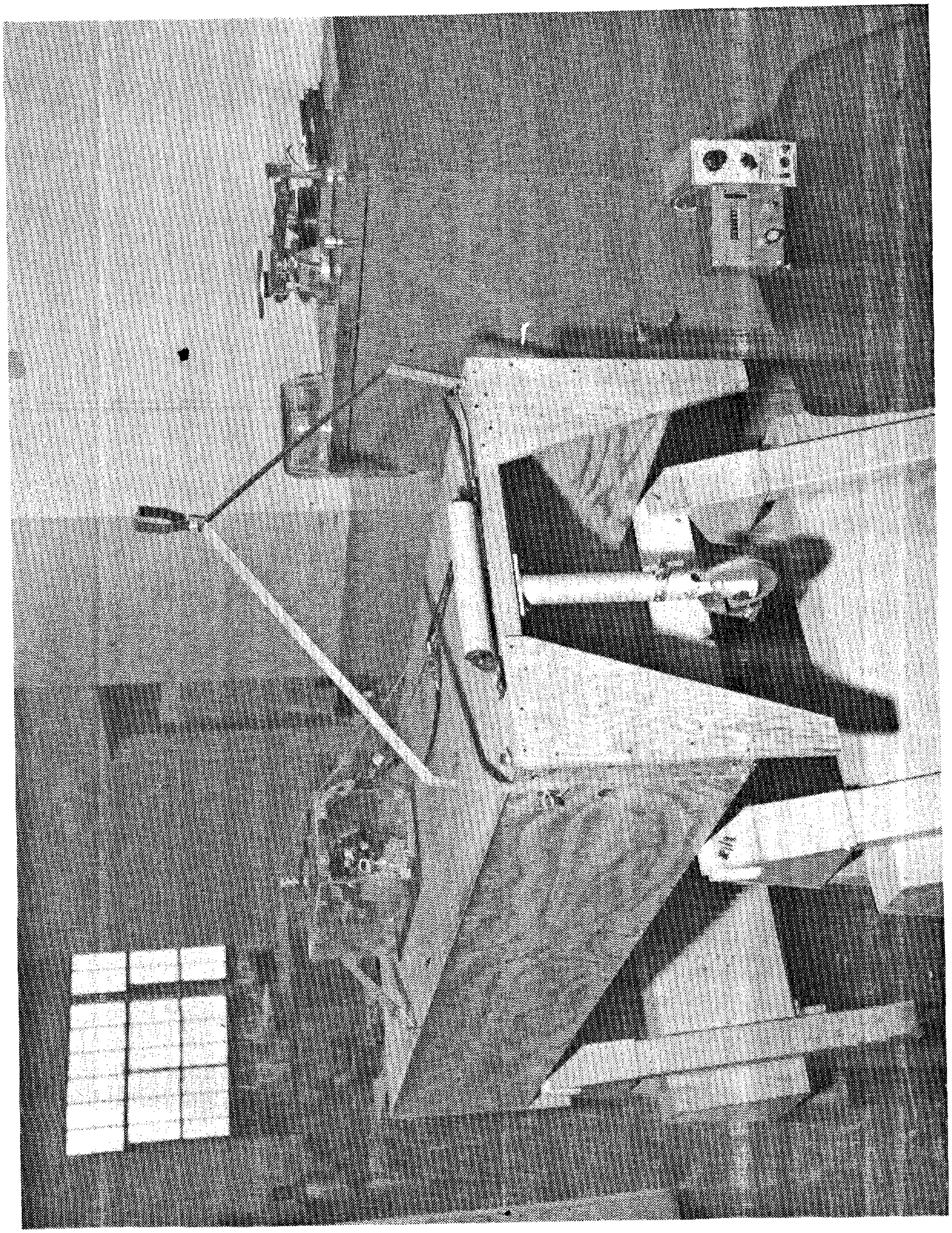

Figure 2-1. Floating Test Rig Components

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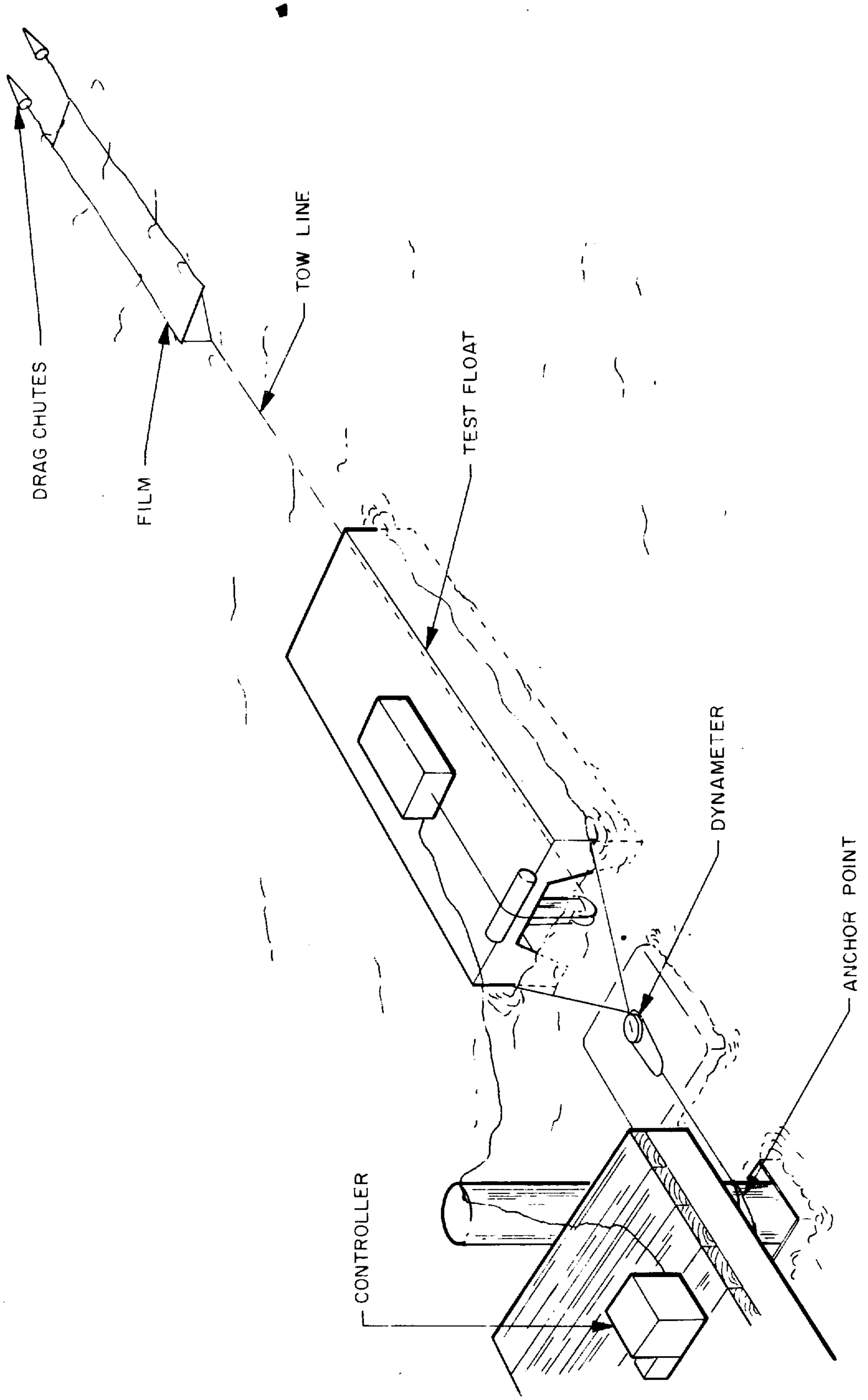

Figure 2-2. Diagram Showing Use of Floating Test Rig

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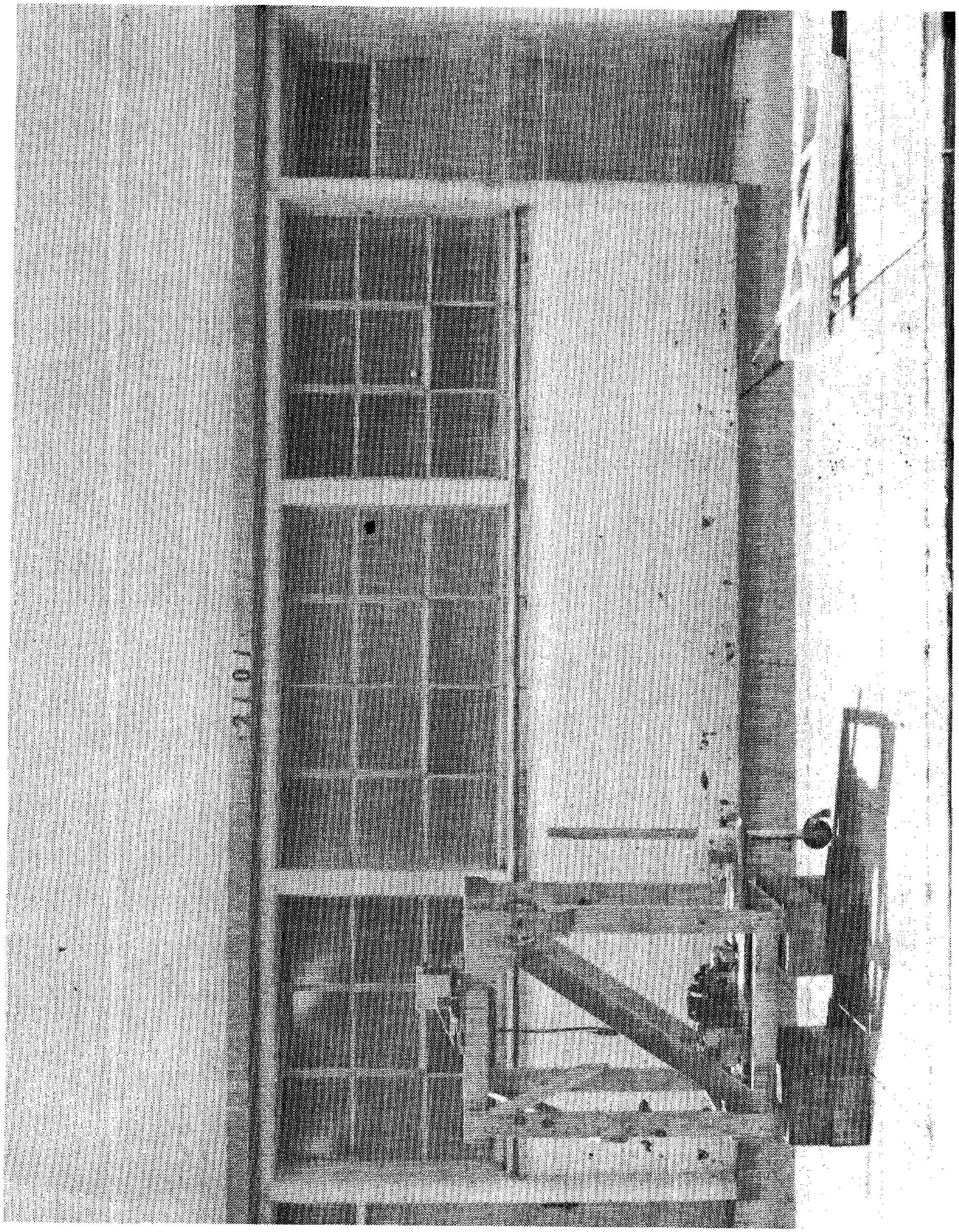

Figure 2-3. Test Apparatus for Determining Coefficient of Film Friction (Catamaran Right Foreground)

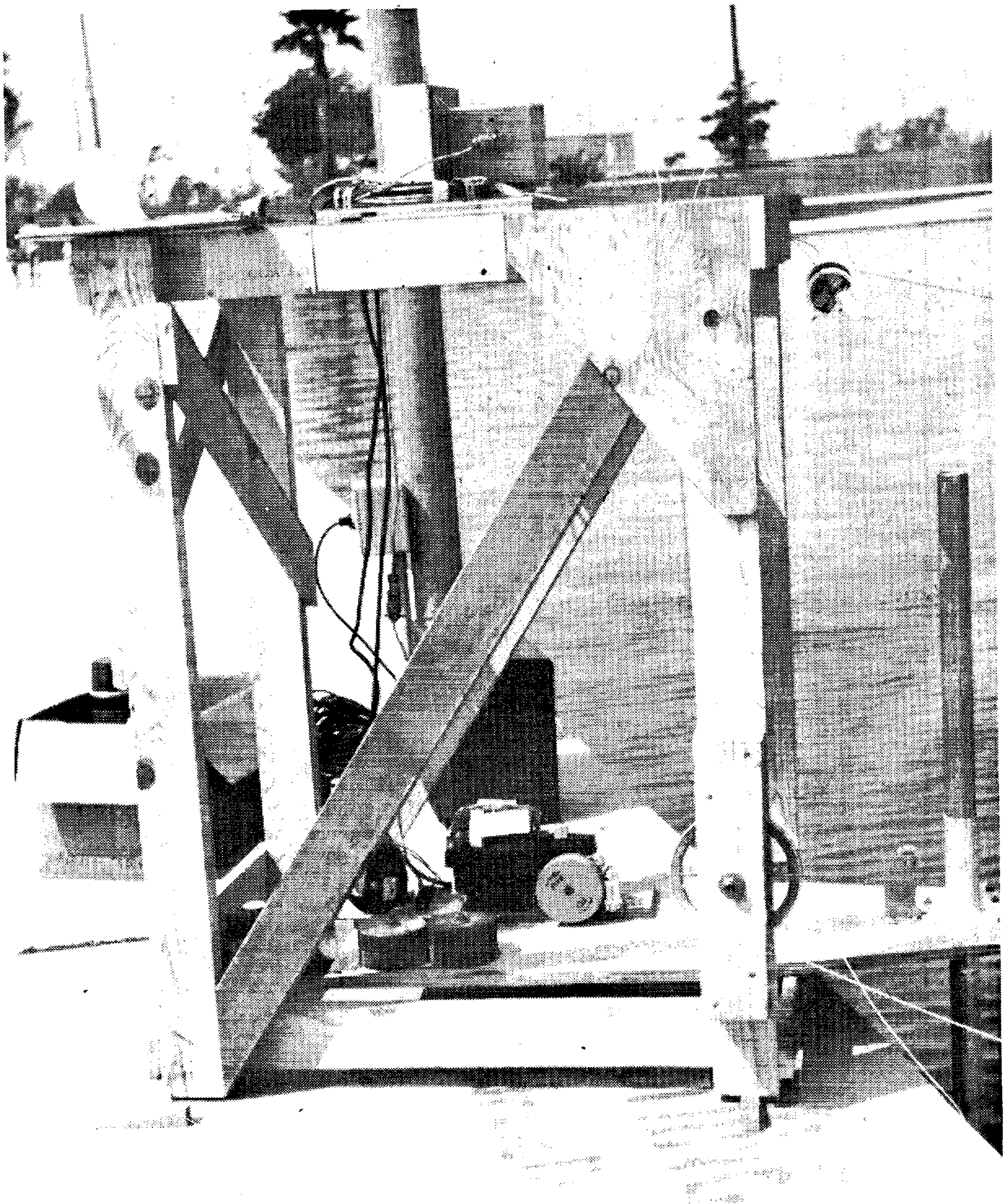

Figure 2-4. Film Drag Rig Mounted Dockside

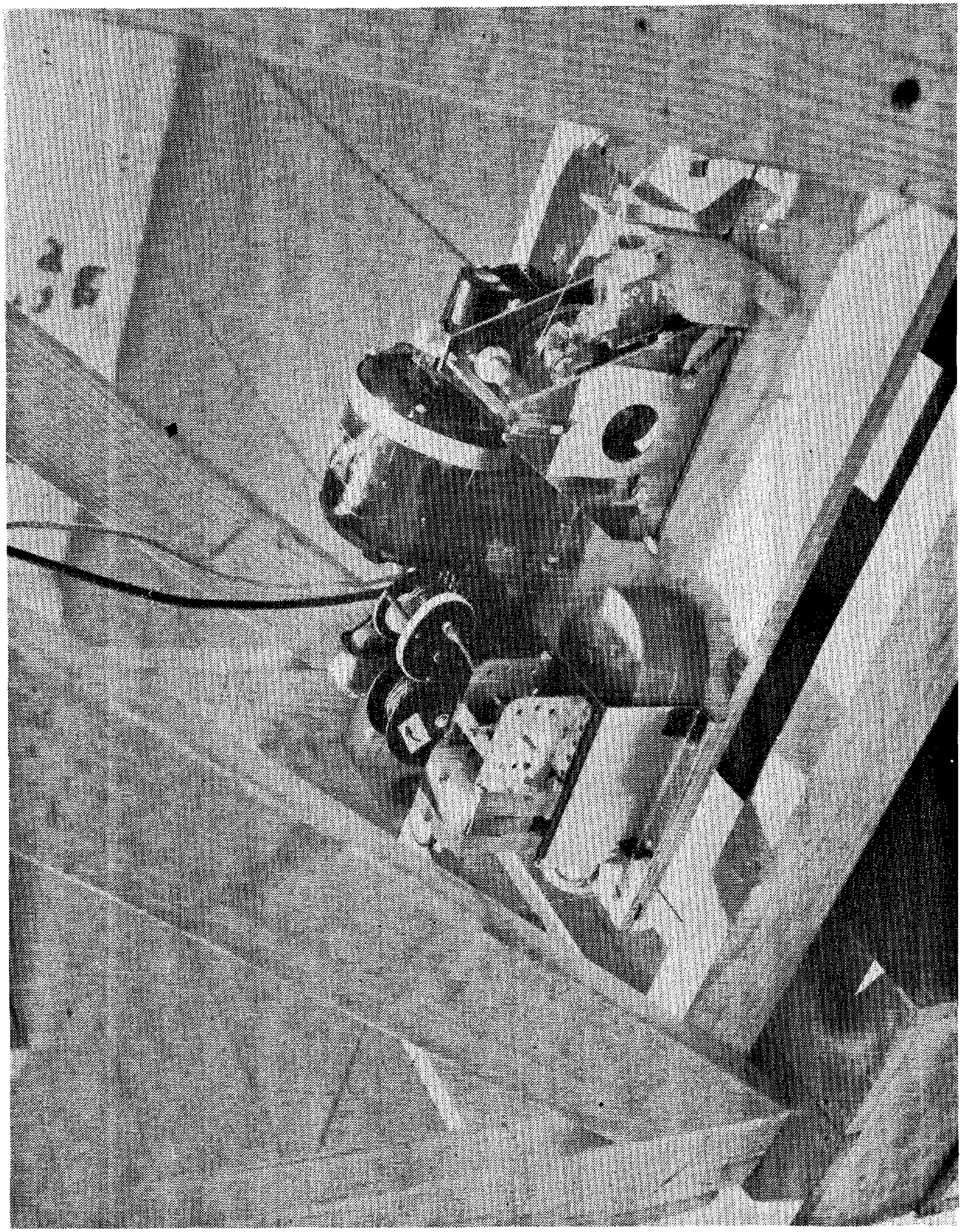

Figure 2-5. Detail of Line Takeup Mechanism

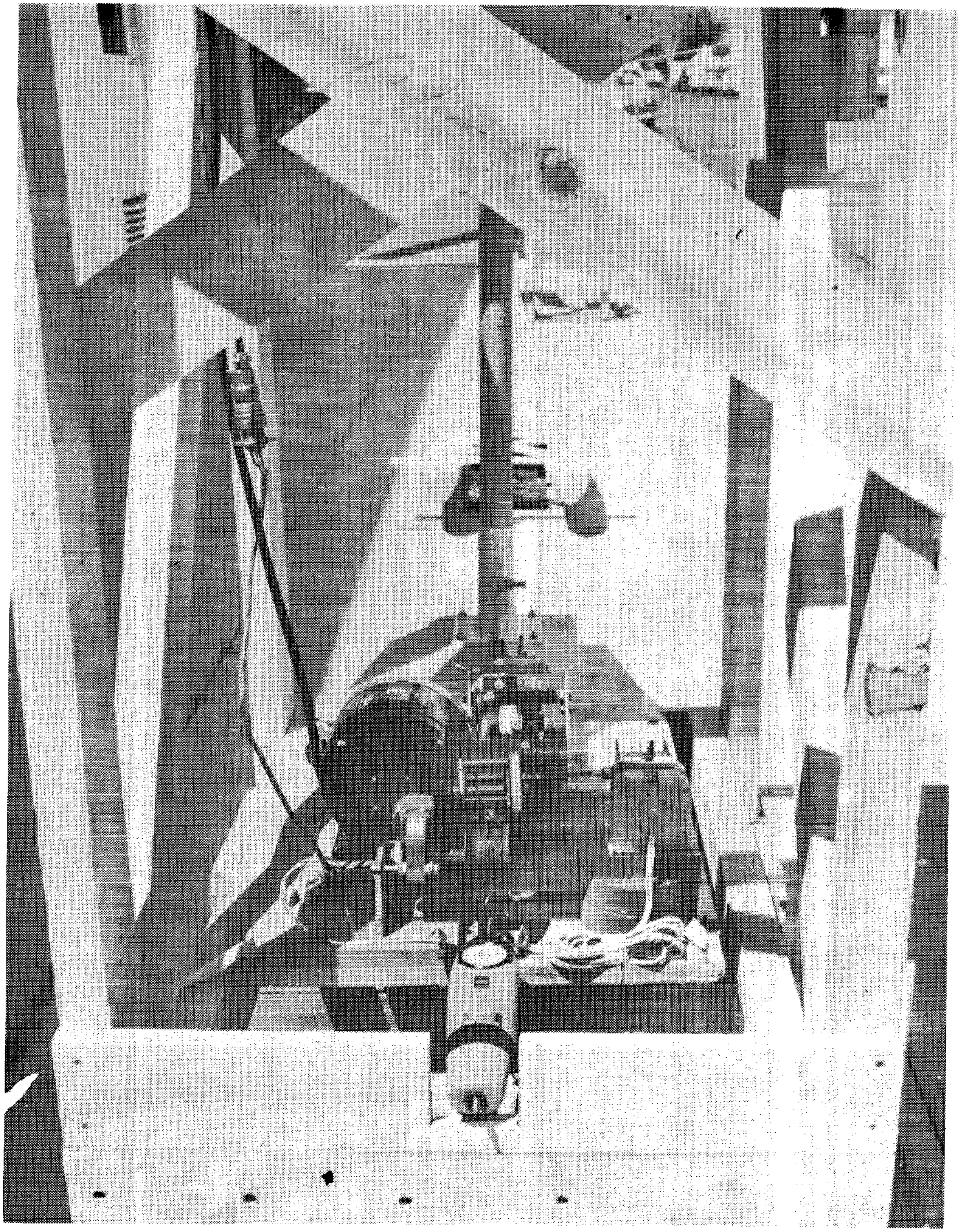

Figure 2-6. Rear View of Apparatus Showing Dynamometer Mounting

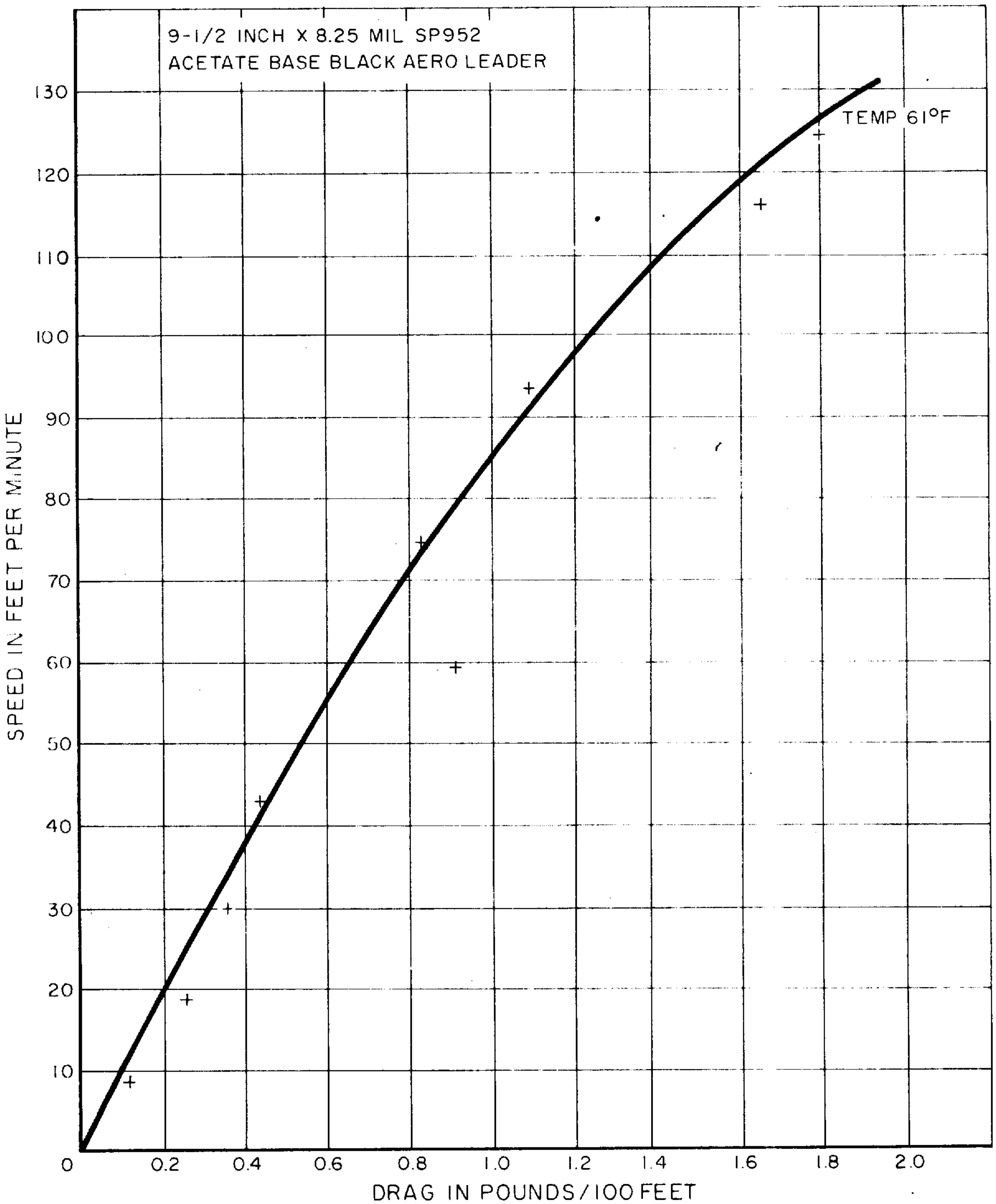

Figure 2-7. Film Drag Coefficients

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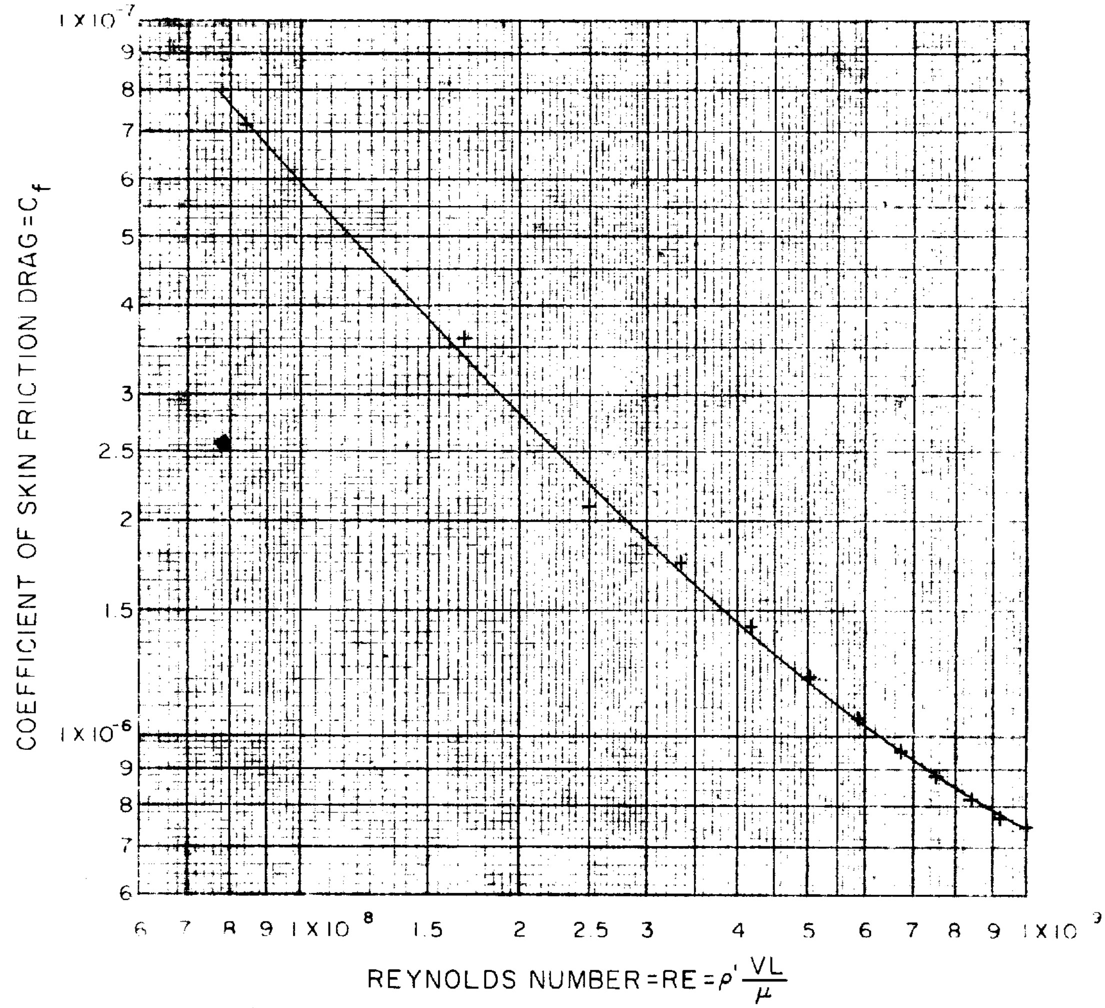

Figure 2-8. Coefficient of Friction Versus Reynolds Numbers

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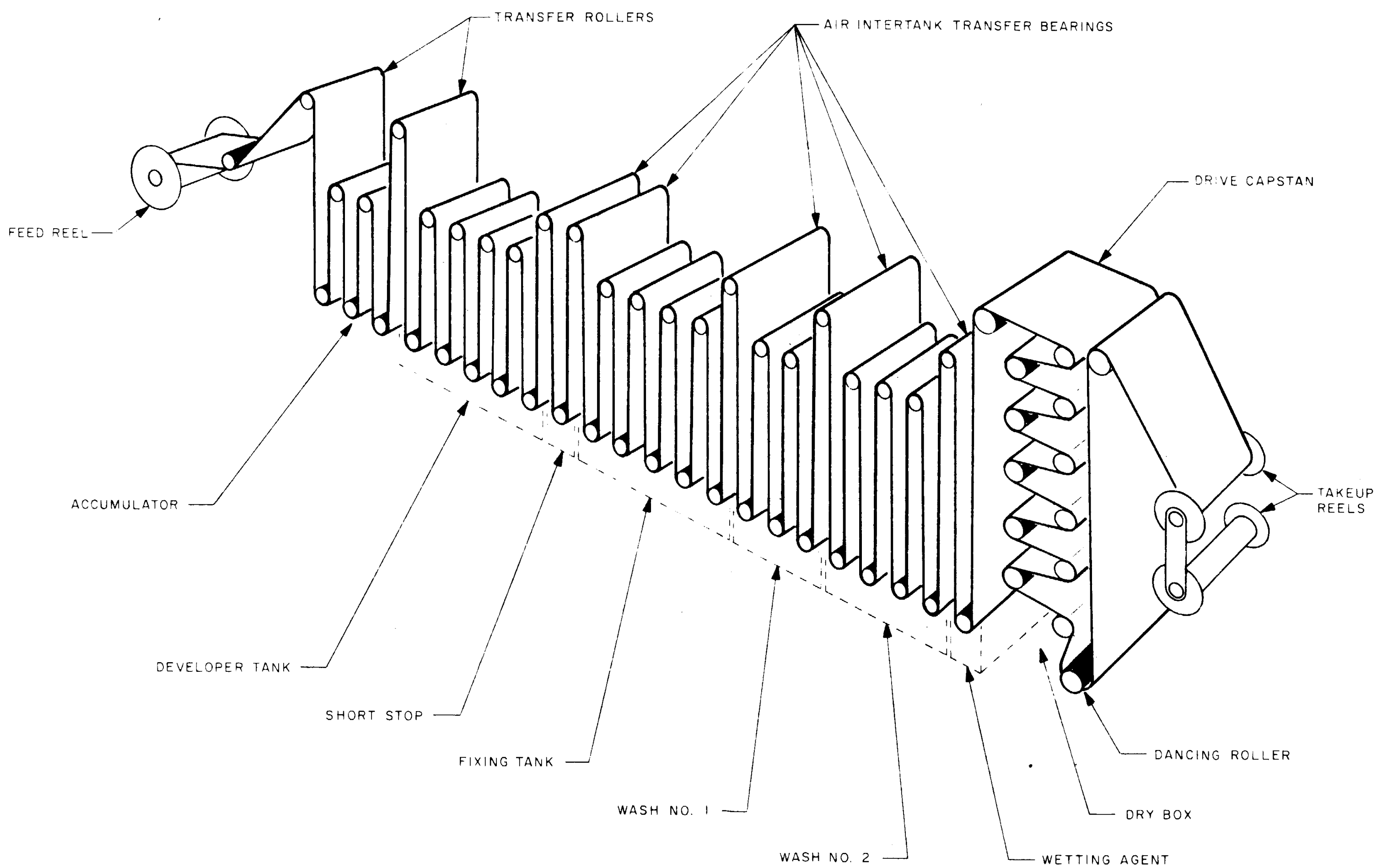

Figure 2-9. Film Path for Hypothetical Processor

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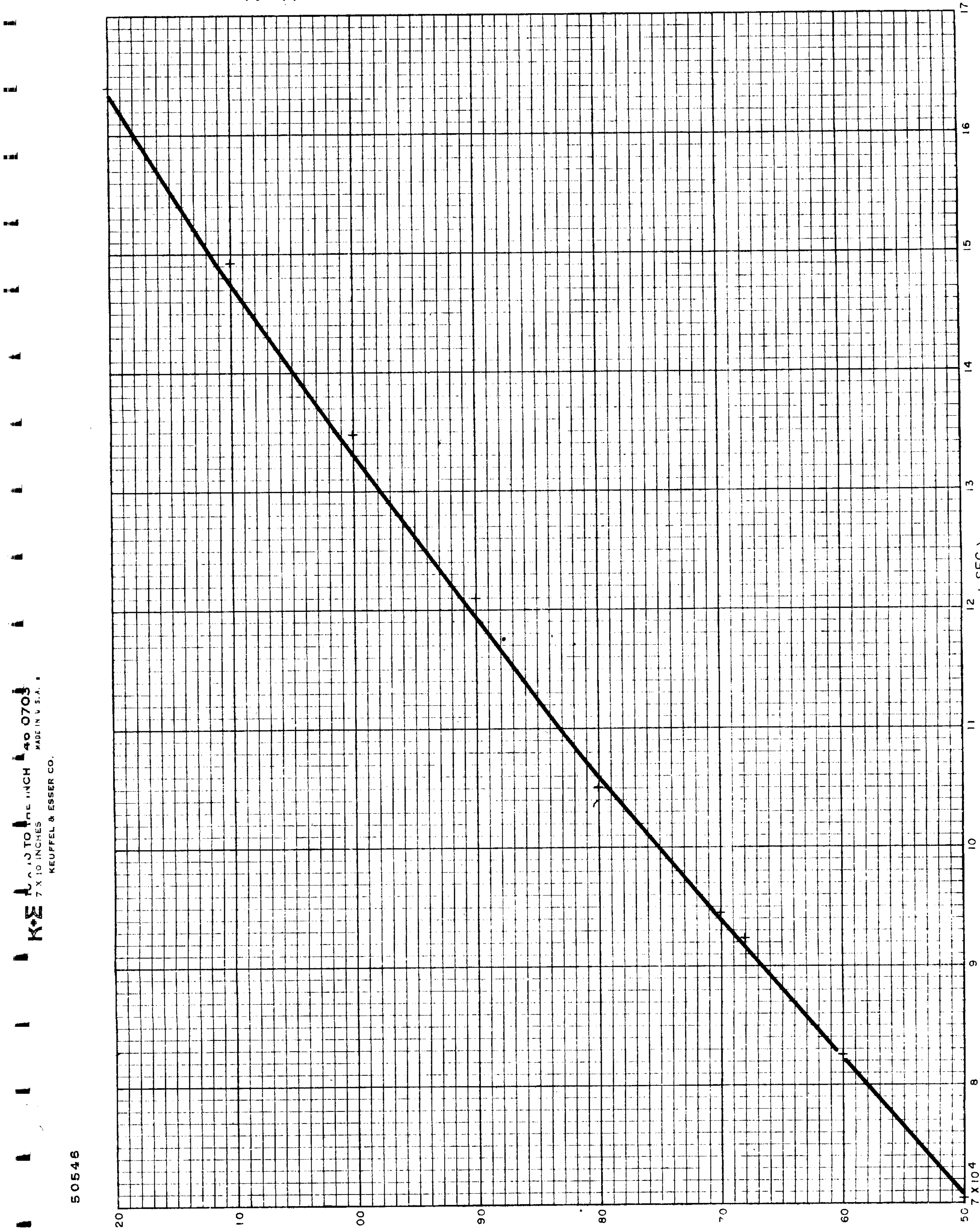

Figure 2-10. Temperature Versus ρ'/μ

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Figure 2-11. Temperature Versus ρ

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NOMOGRAPH I-A
WETTED SURFACE, S

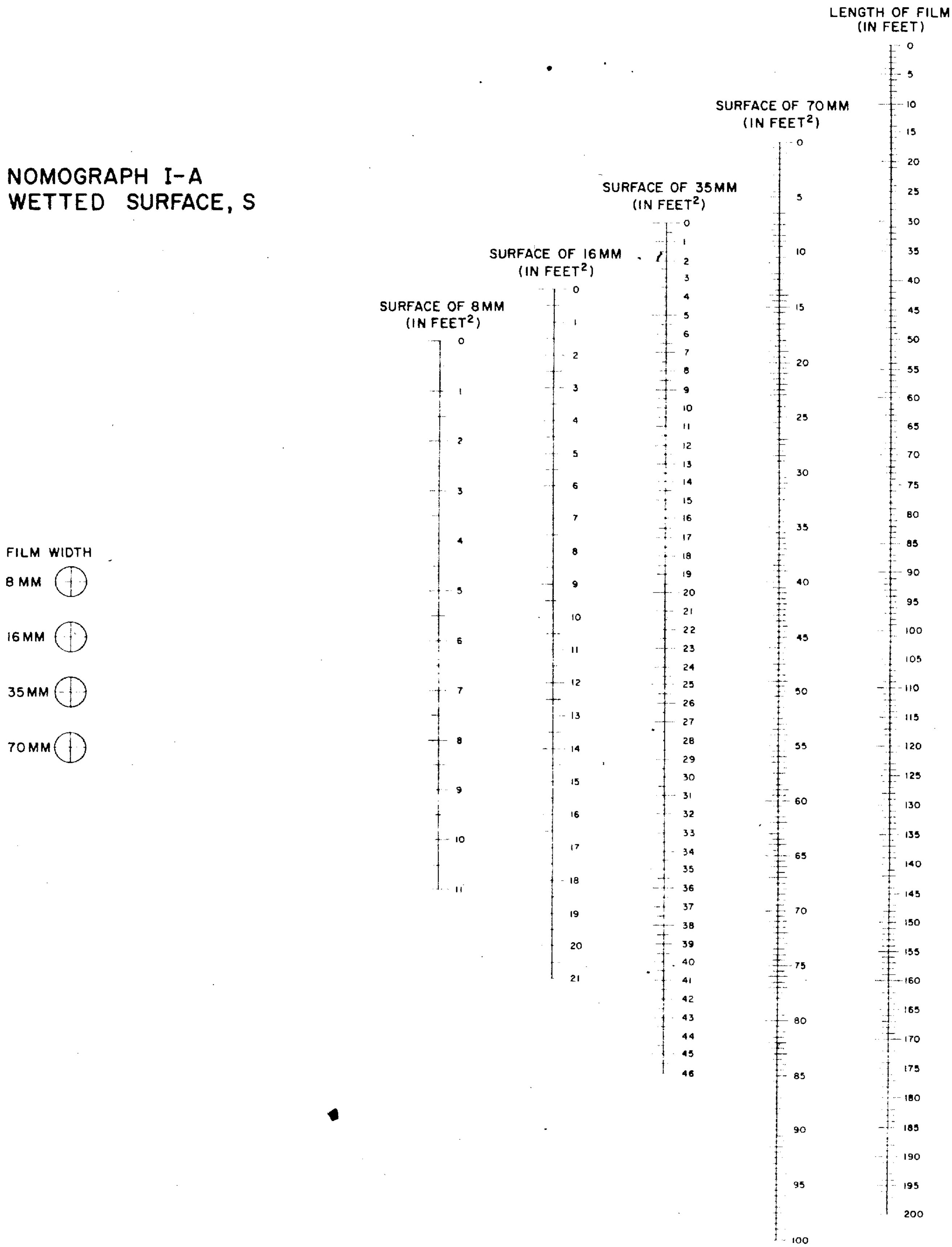

Figure 2-12. Nomograph IA, Wetted Surface, S

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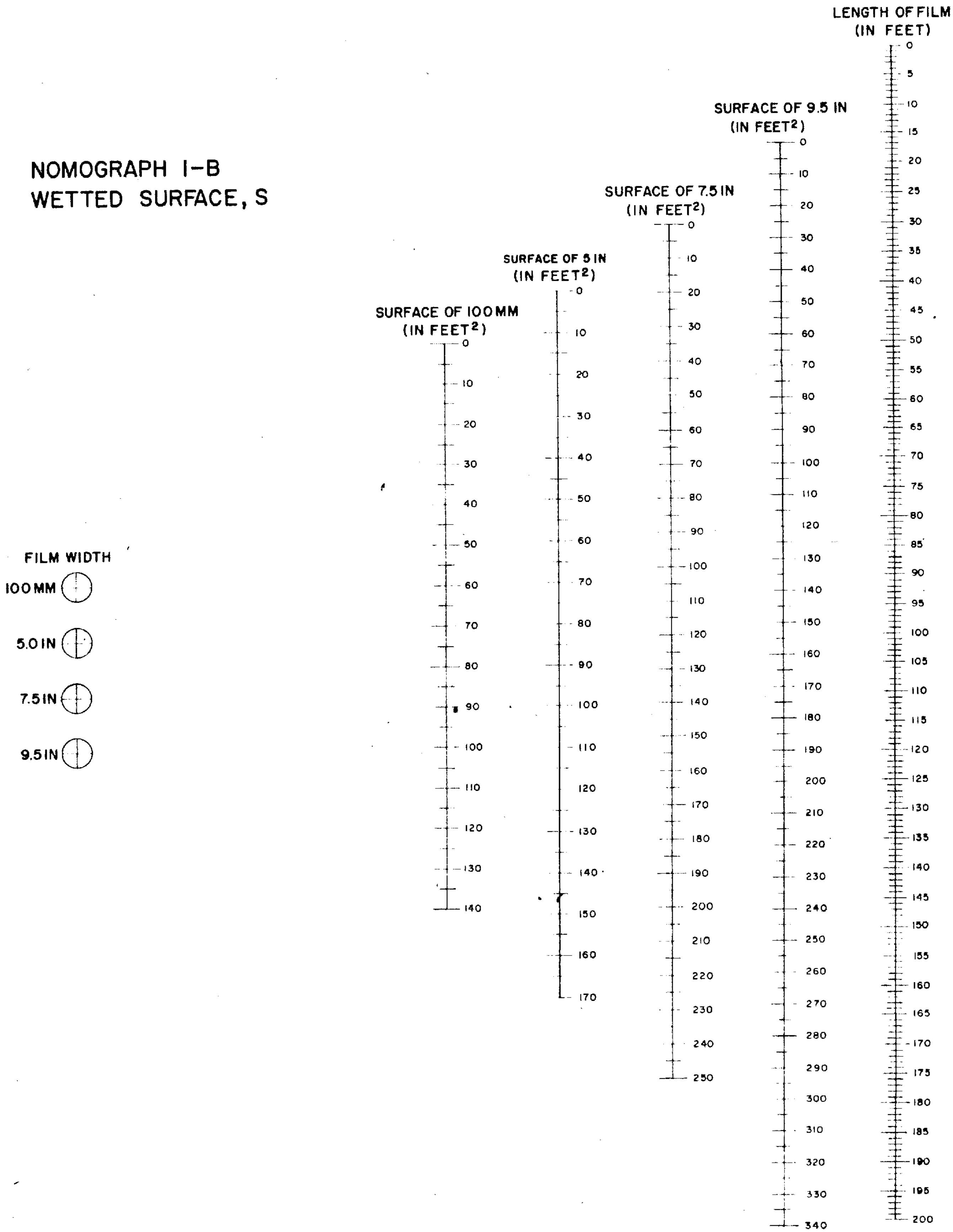

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Figure 2-13. Nomograph IB, Wetted Surface, S

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TABLE 2-1

FILM DRAG COEFFICIENTS

Water Temperature = 61°F

Speed Index	rpm	fpm (Corr.)	Load (Pounds)			
			Drag	/52 ft	/50 ft	/100 ft
100	120	124.0	0.475	1.38	0.90	1.80
90	112	115.7	0.29	1.12	0.83	1.66
80	94	97.1	0.31	0.86	0.55	1.10
70	72	74.4	0.13	0.55	0.42	0.84
60	57	58.7	0.04	0.50	0.46	0.92
50	41.5	42.9	0.03	0.25	0.22	0.44
40	29	30.0	0.04	0.22	0.18	0.36
30	18	18.6	0.03	0.16	0.13	0.26
20	8.5	8.8	0.02	0.08	0.06	0.12

STAT

TABLE 2-2

COEFFICIENT OF FRICTION AND REYNOLDS NUMBERS

Velocity fpm (from Fig. 2-7)	Drag (lbs/100 ft)	C_f	R_e
120	1.65	7.47×10^{-5}	10.05×10^{8}
110	1.43	7.70	9.21
100	1.25	8.15	8.38
90	1.09	8.78	7.54
80	.93	9.48	6.70
70	.80	1.06×10^{-6}	5.86
60	.67	1.21	5.03
50	.55	1.43	4.19
40	.43	1.75	3.35
30	.32	2.09	2.51
20	.22	3.59	1.68
10	.11	7.17	0.84

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TABLE 2-3

HTA-3C PROCESSOR SPECIFICATION SHEET

Station	Capacities			Processing Time at 30 fpm	
	Film		Liquid		
	Ft	In.	Gallons	Min	Sec
Load Magazine*	1200	0	-	-	-
Load Accumulator	40	0	-	1	20
Water Prebath	8	6	17	0	17
Developer Tank/Double	85	0	170	2	50
Short Stop	8	6	17	0	17
Fix Tank	42	6	85	1	25
Wash 1	8	6	17	0	17
Wash 2	42	6	85	1	25
Wash 3	8	6	17	0	17
Drying Compartment	67	0	-	2	14
Takeup Accumulator	14	0	-	0	28
Total Processing	325	0	408	10	50
Dual Takeup Flange (Standard Base) (Thin Base)	1200 each 1800 each				

*Darkroom operation spools above 1800 feet up to 6000 feet in film carts (thin or standard base)
Daylight operation magazines up to 1800 feet (thin base) 1200 feet (standard base)

Processing Capabilities of 0 to 60 fpm
Average Processing Speeds at 75°F (4DS) Original Type 8401/8402 at 30 fpm
(16DR) Duplicate Type 228R/5427 at 40 fpm

GENERAL SPECIFICATIONS

Length	22 feet, 9 inches
Height	8 feet, 11 inches (10 feet, 4 inches with rods extended)
Width (Wet Section)	3 feet
Width (Drier Section)	4 feet, 2 inches
Power Requirements	120/208-volt, 3-phase, 4-wire, 60-cycle, 115-amp
Water Supply to Blender (Hot water, 110°F minimum) (Chilled water, 55°F maximum)	25 gpm at 45 psi (1-inch input pipe with capacity of 30 gpm)
Drain	50 gpm (4-inch minimum drain size)
Drier Air Exhaust	1700 cfm (maximum)

TABLE 2-4

HTA-3CM PROCESSOR SPECIFICATION SHEET

Station	Capacities			Processing Time at 30 fpm	
	Film		Liquid		
	Ft	In.	Gallons	Min	Sec
Load Magazine*	1200	0	-	-	-
Load Accumulator	18	0	-	0	36
Water Prebath	6	10	18	0	14
Developer Tank	61	6	115	2	5
Short Stop	6	10	11	0	14
Fix Tank	34	2	65	1	8
Wash 1	6	10	14	0	14
Wash 2	34	2	63	1	8
Wash 3	6	10	18	0	14
Drying Compartment	32	9	-	1	6
Takeup Accumulator	9	6	-	0	19
Total Processing	217	5	304	7	18
Dual Takeup Flange (Standard Base)	1200 each				
(Thin Base)	1800 each				

*Darkroom operation spools above 1800 feet up to 6000 feet in film carts (thin or standard base)
Daylight operation magazines up to 1800 feet (thin base) 1200 feet (standard base)

Processing Capabilities of 0 to 60 fpm
Average Processing Speeds at 75°F (4DS) Original Type 8401/8402 at 25 fpm
(16DR) Duplicate Type 228R/5427 at 30 fpm

GENERAL SPECIFICATIONS

Length	17 feet, 10 inches
Height	6 feet, 4 inches (8 feet with rods extended)
Width (Wet Section)	3 feet
Width (Drier Section)	4 feet, 2 inches
Power Requirements	120/208-volt, 3-phase, 4-wire, 60-cycle, 75-amp
Water Supply to Blender (Hot water, 110°F minimum) (Chilled water, 55°F maximum)	25 gpm at 40 psi (1-inch input pipe with capacity of 30 gpm)
Drain	30 gpm (4-inch minimum drain size)
Drier Air Exhaust	1700 cfm (maximum)

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TABLE 2-5

CONTROLLABLE DEVELOPMENT PROCESSOR DATA SHEET

Station	Capacities			Temp.	Processing Time at 6.6 fpm	
	Film		Liquid			
	Feet	Inches	Gallons	°F	Minutes	Seconds
Load	2	7	-	-	0	23
Accum. (Total)	36	7	-	-	5	29
Accum. (only)	16	8	-	-	2	30
Prewet	2	7-1/2	7.9	68	0	23
Controllable Developer	13	5-3/8	192	68	2	1
Stop	21	6-1/2	58.3	68	3	14
Fix 1	21	6-1/2	58.3	68	3	14
Fix 2	44	5-3/4	111.0	68	6	40
Rinse	11	6-3/4	40.5	68	1	44
Wash 1	21	6-1/2	58.3	68	3	14
Wash 2	21	6-1/2	58.3	68	3	14
Wash 3	31	0	84.7	68	4	39
Wetting Agent	11	6-3/4	32.9	68	1	44
Drier	15	0	-	110-150	2	15
Takeup	3	9	-	-	0	34
TOTAL	258	9-1/8	702.2	-	38	48

WATER REQUIREMENTS

Wash tank water, 16 gpm at 68° to 70°F, supplied from 50° ±0.5°F and 140° ±0.5°F at 50 psi
Hot water at 140°F (approximately). Minimum of 50 to 60 gpm for flushing only.

DRAIN REQUIREMENTS

600 gallons in 6 minutes (machine drain, 3-inch pipe)

AIR REQUIREMENTS

Air-bearings, 3200 cfm
Dry box (inlet), 2000 cfm
Exhaust ducts; 2 required to eliminate air-bearing and dry-box air.

TABLE 2-6

HTA-5 PROCESSOR DATA SHEET

Station	Capacities			Temp.	Processing Time at 20 fpm	
	Film		Liquid			
	Feet	Inches	Gallons	°F	Minutes	Seconds
Load to Accum.	5	0	-	-	0	15
Accumulator	30	0	-	-	1	30
Developer	41	0	121.5	85	2	3
Rinse	9	0	26.5	85	0	27
Fix	41	0	121.5	85	2	3
Wash 1	25	0	73.5	85	1	15
Wash 2	33	0	96.5	85	1	39
Final Wash	9	0	26.5	85	0	27
Dry Box	20	0	-	130	1	0
Dry Box to Takeup	2	6	-	-	0	8
TOTAL	215	6	466.0	-	10	41

FUNCTION

To process 70mm to 9-1/2-inch wide films of Types SO-4400, SO-4404, SO-8450, SO-243, SO-5427, SO-8402, and 1153 at a temperature of 85°F with D-19 developer at speeds up to 20 fpm.

SENSITOMETRIC QUALITY

A step wedge exposed on a Hernfeld sensitometer, or equivalent, on film types SO-8450 and SO-8402 is to produce a gamma of not less than 1.00 when processed as above.

DRIER

Air, 480 cfm at a temperature of 130°F and a relative humidity of 45 percent ±5 percent. Filtered to exclude 85 percent of all particles larger than 3 microns.

WATER REQUIREMENTS

Chilled water, 20 gpm at pressure of 3 psi and a temperature of 45°F. All liquids filtered to exclude 85 percent of all particles larger than 3 microns.

TEMPERATURE CONTROL

Developer and Fixing Solutions to ±0.25°F. Washes to ±2.5°F.

TABLE 2-7

HYPOTHETICAL PROCESSOR DATA SHEET

Station	Film	Temp	Processing Time at 20 fpm		Number of Bearings			Load per Bearing (max)
	Feet	°F	Min	Sec	Roller	Liq.	Air	Pounds
Accumulator	50	Amb	2	30	7	-	-	12.17
Developer	25 to 43-1/3	88	2	10 (max)	-	9	-	1.37
Short Stop	7-2/3	88	0	23	-	1	-	1.63
Fix	43-1/3	88	2	10	-	9	-	3.03
Wash 1	25	88	1	15	-	5	-	3.92
Wash 2	33-1/3	88	1	40	-	7	-	5.10
Wetting Agent	7-2/3	88	0	23	-	1	-	5.16
Dry Box	30	130	1	30	-	-	11	2.08
Dry Box to Takeup	3	Amb	0	9	1	-	-	4.88
Intertank Transfer Bearings	0	-	0	0	-	-	5	5.13
Drive Capstan	-	-	-	-	1	-	-	6.47
Dancing Roller	-	-	-	-	1	-	-	3.39
TOTAL	243-1/3	-	12	10	10	32	16	-

TABLE 2-8

TEMPERATURE VERSUS ρ'/μ

Temperature		ρ'	μ	ρ'/μ
°F	°C	g/ml	centipoise	($x10^4$)
50	10.00	0.99973	1.3077	7.07
60	15.56	0.99904	1.1240	8.26
68	20.00	0.99823	1.0050	9.23
70	21.11	0.99800	0.9785	9.48
80	26.67	0.99663	0.8608	10.51
90	32.22	0.99498	0.7645	12.09
100	37.78	0.99307	0.6843	13.48
110	43.33	0.99093	0.6171	14.92
120	48.89	0.98857	0.5595	16.42

TABLE 2-9

TEMPERATURE VERSUS ρ

Temperature		Density	ρ
°F	°C	g/ml	slugs/ft^3 (X $\overline{\frac{1}{32.174}}$)
50	10.00	0.99973	1.942
60	15.56	0.99904	1.940
68	20.00	0.99823	1.939
70	21.11	0.99800	1.938
80	26.67	0.99663	1.937
90	32.22	0.99498	1.932
100	37.78	0.99307	1.929
110	43.33	0.99093	1.925
120	48.89	0.98857	1.920

TABLE 2-10

WETTED SURFACE, S, FOR DIFFERENT FILM SIZES AND LENGTHS

Number of Feet	Nomograph IA				Nomograph IB			
	8mm	16mm	35mm	70mm	100mm	5 inch	7.5 inch	9.5 inch
10	0.53	1.05	2.30	4.59	6.56	8.33	12.50	15.83
20	1.05	2.10	4.59	9.19	13.12	16.67	25.00	31.67
30	1.58	3.15	6.89	13.78	19.69	25.00	37.50	47.50
40	2.10	4.20	9.19	18.37	26.25	33.33	50.00	63.33
50	2.63	5.25	11.48	22.97	32.81	41.67	62.50	79.17
60	3.15	6.30	13.78	27.56	39.37	50.00	75.00	95.00
70	3.67	7.35	16.08	32.15	45.93	58.33	87.50	110.83
80	4.20	8.40	18.37	36.75	52.49	66.67	100.00	126.67
90	4.72	9.45	20.67	41.34	59.05	75.00	112.50	142.50
100	5.25	10.50	22.97	45.93	65.62	83.33	125.00	158.33
110	5.77	11.55	25.26	50.53	72.18	91.67	137.50	174.17
120	6.30	12.60	27.56	55.12	78.74	100.00	150.00	190.00
130	6.82	13.65	29.86	59.71	85.30	108.33	162.50	205.83
140	7.35	14.70	32.15	64.31	91.86	116.67	175.00	221.67
150	7.87	15.75	34.45	68.90	98.42	125.00	187.50	237.50
160	8.40	16.80	36.75	73.49	104.99	133.33	200.00	253.33
170	8.92	17.85	39.04	78.08	111.55	141.67	212.50	269.17
180	9.45	18.90	41.34	82.68	118.11	150.00	225.00	285.00
190	9.97	19.95	43.64	87.27	124.67	158.33	237.50	300.84
200	10.50	21.00	45.93	91.86	131.23	166.67	250.00	316.67

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